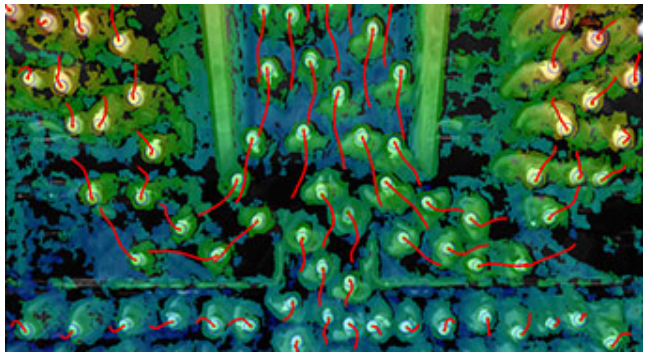
JÜLICH
FORSCHUNGSZENTRUM

Fire Simulation

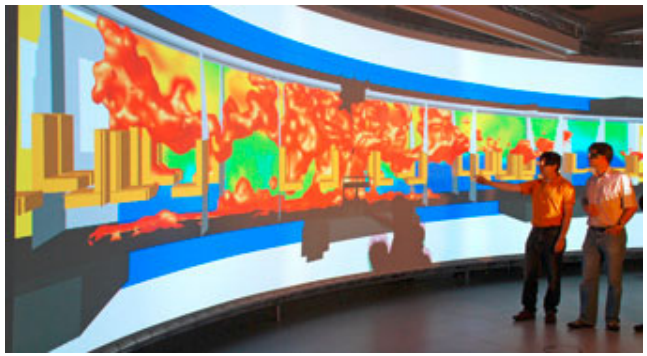
June 15, 2016 | Marc Fehling | Jülich Supercomputing Centre (JSC)

JSC - Division Civil Security and Traffic (CST)

- **Pedestrian dynamics**
  - Experiments, modeling, simulation
  - Civil Security at major events
  - Assessment of traffic installations
- **Traffic**
  - Large–scale traffic simulation



- **Fire simulation**
  - Parallel and adaptive methods for fire simulations
  - Safety in underground stations
  - PIV experiments for validation



Fire Group Activities: Simulation

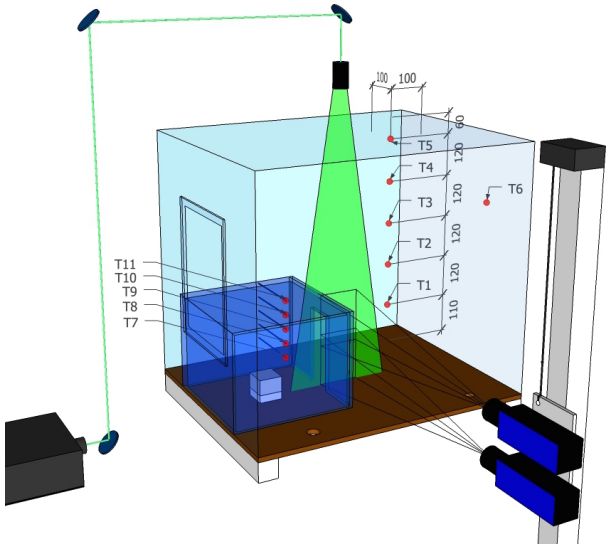
- Simulations of smoke and fire spread
  - Modeling of combustion, radiation, heat transfer, and smoke propagation
  - Use of common software (FDS, FireFOAM), contribute to its development
  - Write own software with various specializations
- For use on desktop machines, GPU nodes, and supercomputers

Jureca Cluster

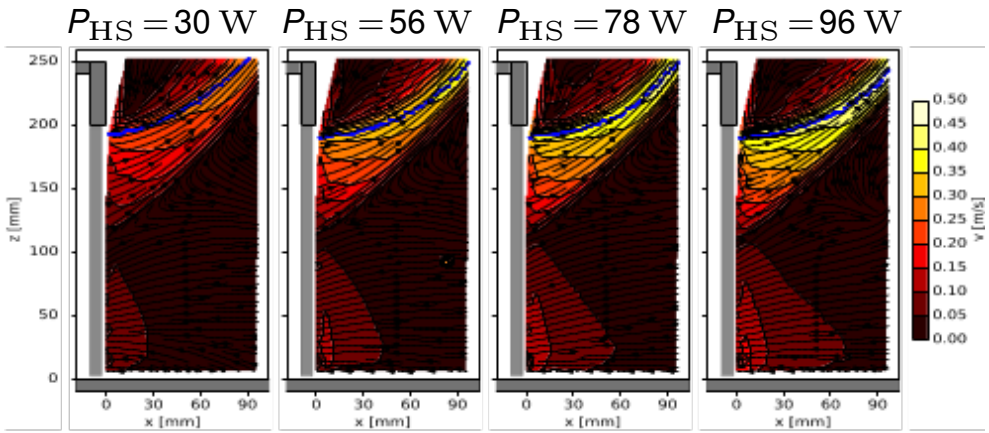
Nvidia Tesla K80

Fire Group Activities: Experiments

- Particle Image Velocimetry (PIV) experiments
  - Electrically heated source as driver
  - Seeding particles for flow visualization
  - Laser for particle illumination, cameras for recording
  - Temperature recording with thermocouples
- Using both commercial and self–written software for evaluation and simulation/prediction



Door width 40mm

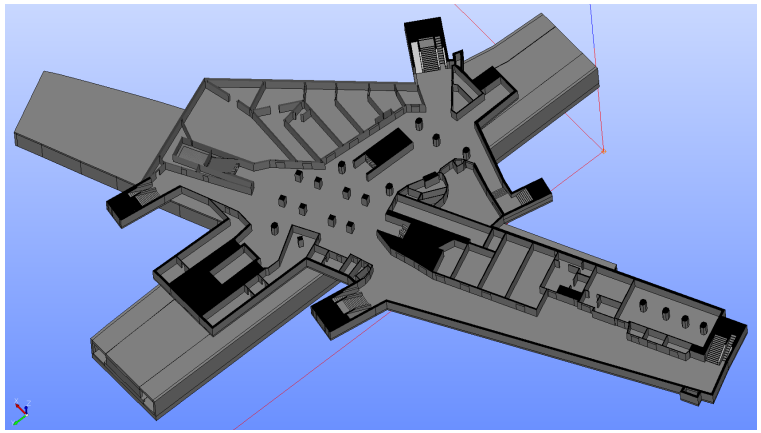


Fire Group Activities: Project Orpheus

ORPHEUS

Optimierung der **R**auchableitung und **P**ersonenführung in U-Bahn**h**öfen: **E**xperimente **u**nd **S**imulationen

- Smoke and fire spread in complex metro stations
  - High dimensional parameter space for fire scenarios, including underground climate
- Pedestrian situation and behavior at evacuation
- Risk analysis regarding human safety



Common Equations for Smoke Spread

- Smoke spread with incompressible Navier–Stokes (NS) equations

$$\nabla \cdot \mathbf{u} = 0$$

$$\rho \left[\partial_t \mathbf{u} + (\mathbf{u} \cdot \nabla)\mathbf{u}\right] + \nabla p - \nabla(2\,\nu\,\epsilon_{ij}(\mathbf{u})) = \mathbf{f}(T)$$

$$\rho \left[\partial_t T + (\mathbf{u} \cdot \nabla) T\right] - 2\,\nu\,\epsilon_{ij}(\mathbf{u}) : \nabla \mathbf{u} - \nabla \cdot \left(\mathrm{Pr}^{-1} \nu \nabla T\right) = q$$

with symmetric gradient $\epsilon_{ij}(\mathbf{u}) = \frac{1}{2}\left[\nabla \mathbf{u} + (\nabla \mathbf{u})^T\right]$

- Turbulence model: Smagorinsky–Lilly LES [6]

$$\nu = \nu_{mol} + \nu_{turb} \qquad \text{with} \qquad \nu_{turb} = (C_s h)^2 \left|\left|\epsilon_{ij}(\mathbf{u})\right|\right|_2$$

Fire Dynamics Simulator

FDS-SMV

Fire **D**ynamics **S**imulator & **Sm**oke**v**iew

- Mainly developed at *National Institute of Standards and Technology* (NIST)
- Provides simulation and visualization framework
- First public release in 2000, written in `Fortran`
- Quasi–standard in fire protection engineering
- Well documented: $\rightarrow$ https://pages.nist.gov/fds-smv/

- Uses Finite Difference Method (FDM) for NS equations
- Elaborated models for combustion and radiation

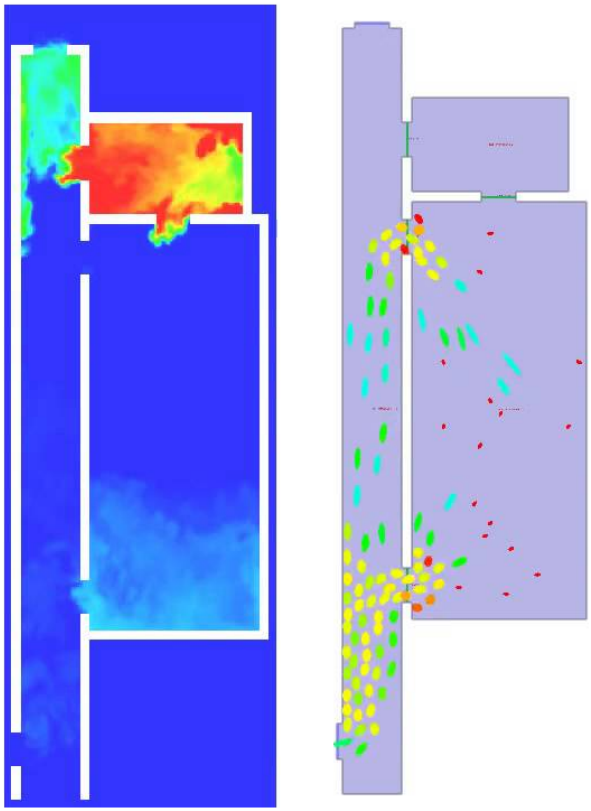
FDS and Evacuation

- Agent–based egress calculation of human beings
- Evacuation module available for `FDS` (`FDS+Evac`)
  - Just for routing, no interaction of agents with fire
- Use locally developed framework `JuPedSim` for more flexibility
- Agent's motion influenced by current smoke situation

  → Smoke sensor

JuPedSim

Juelich **Ped**estrian **Sim**ulator



JuROr

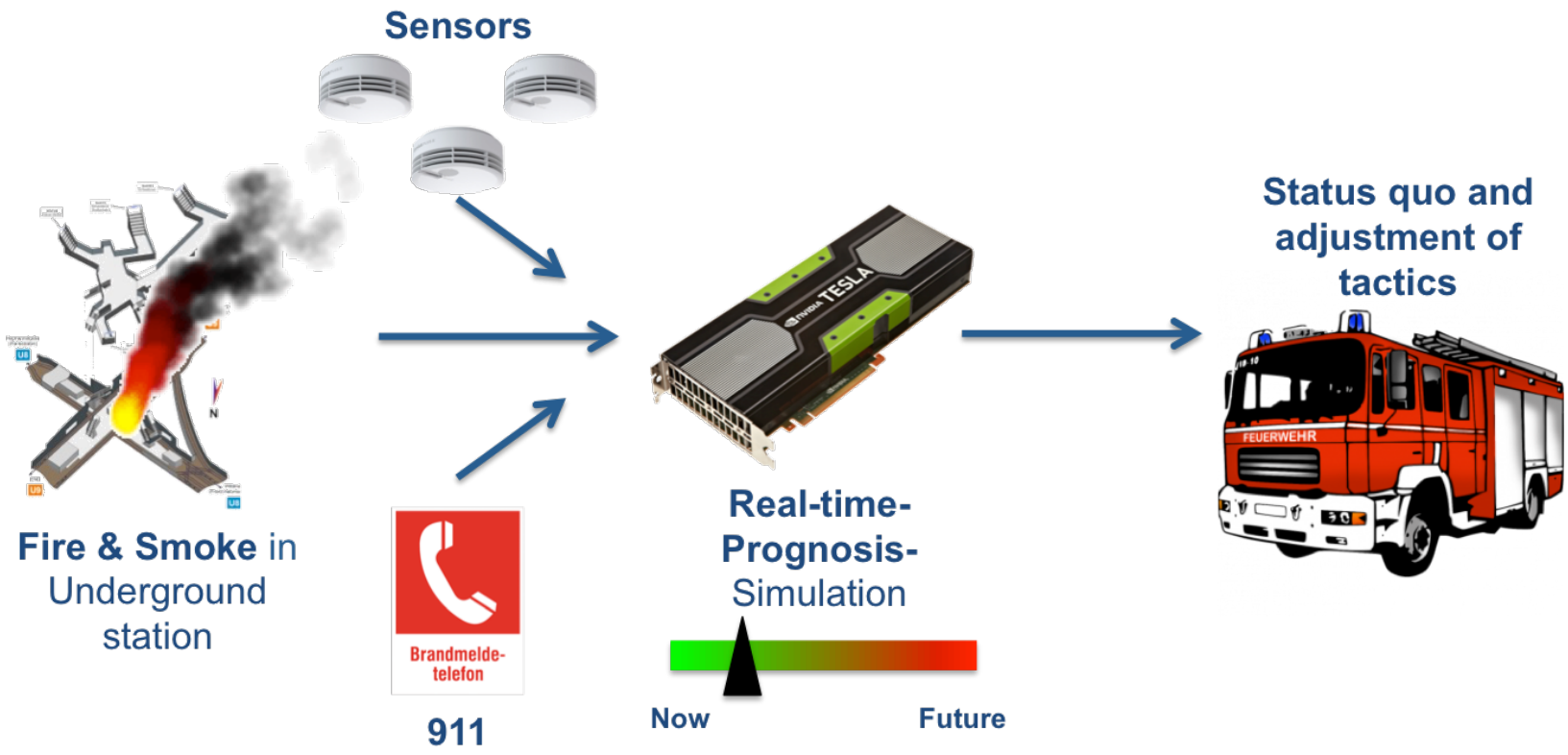
Juelich's **R**eal–time simulation within **Or**pheus

- Aim: Real–time prognosis of fire spread in emergencies
- Help fire fighters to evaluate situation while reaching fire
- Run simulations on (affordable) GPUs

- Uses `OpenACC` API for high flexibility, no external libraries
- Current extent: Flow solver for NS equations with FDM
- Current state: Verification with manufactured solutions

JuROr: Motivation

- Take current situation as boundary values for prognosis



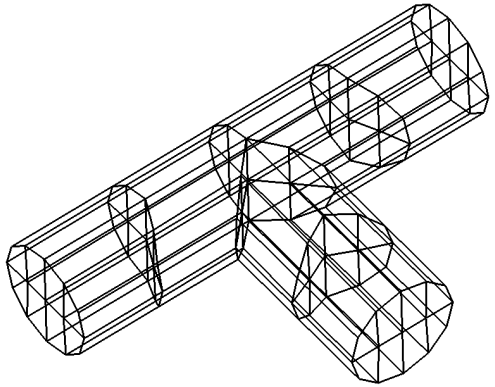
JuFire

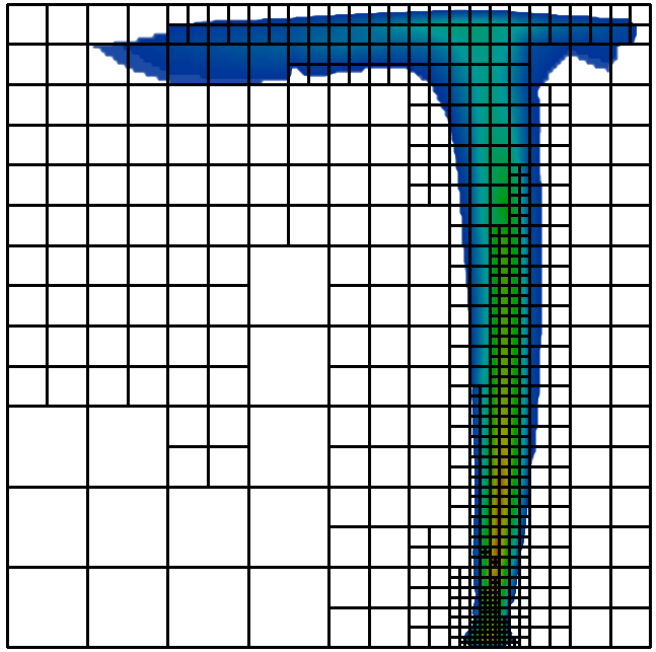
- Investigate applicability of Finite Element Methods (FEM) for fire simulation
- Current state: Verification with manufactured solutions
- Use open–source library deal.II [1]
  - ”Toolbox” for the creation of FEM codes

Differential **E**quations **A**nalysis **L**ibrary

JuFire: Features

- Unstructured grids
- Adaptive refinement in both space and polynomial degree of shape functions (*hp* adaptivity)
- Utilize `CAD` models as manifolds for mesh refinement
  - Use `OpenCASCADE` library
- Continuous and discontinuous Galerkin methods (CG/DG)
- MPI parallelization





Thank you for your attention!

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Fire Simulation: Addendum

June 15, 2016 | Marc Fehling | Jülich Supercomputing Centre (JSC)

JuROr: Algorithm

- Algorithm following Glimberg's Ansatz [3]
- Regular grid with data in cell centers
- Finite Difference Method: Central differences in space
- Time discretization: Fractional step method
  - Advection: $\partial_t \mathbf{u}_1 = -(\mathbf{u}_1 \cdot \nabla)\mathbf{u}_1$ Semi–Langrangian method
  - Diffusion: $\partial_t \mathbf{u}_2 = \nu \nabla^2 \mathbf{u}_2$ implicit Jacobi method
  - Sources: $\partial_t \mathbf{u}_3 = \mathbf{f}(T)$ explicit Euler (BD) in time
  - Pressure: $\partial_t \mathbf{u}_4 = -\rho^{-1} \nabla p$ Incompressibility, Multigrid, Jacobi and Projection
- Boussinesq–approximation [2]: $\rho \approx \rho_0 [1 - \beta(T - T_0)]$
  Apply on buoyancy force density: $\mathbf{f}(T) = \rho(T)\mathbf{g}$,
  thus drop second order terms in NS eqs.

JuFire: Algorithm

- Time evolution with backward differentiation formula (BDF)
- Taylor–Hood elements [7]: $(\mathbf{u}, p) \in Q_{k+1}^{\dim} \times Q_k$
- Decoupling of $(\mathbf{u}, p)$ by projection scheme
  - Leads to the pressure–Poisson equation
- Stabilization of momentum equation
  - Taylor–Galerkin stabilization [5] for Taylor–Hood elements
    - Additional diffusion in flow direction
  - Grad–div stabilization [4] to enforce $\nabla \cdot \mathbf{u} = 0$
- Neumann series for fast matrix assembly
- Boussinesq approximation for buoyancy force density